Seminar organized by Graduate Program in Spintronics

"Spin-Orbitronics: Interfacial Design of Spintronic Materials and Devices"

Speaker: Professor Geoffrey Beach (Massachusetts Institute of Technology)

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Venue: Room A401
Laboratory for Nanoelectronics and Spintronics, RIEC
(Katahira campus)

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Spin-Orbitronics: Interfacial Design of Spintronic Materials and Devices

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There is great interest in electrically manipulating the magnetization in nanoscale materials for high-performance memory and logic device applications. In this talk I will describe recently-discovered mechanisms, based on symmetry breaking and spin-orbit coupling at interfaces, whereby the magnetization can be controlled using very low currents[1-6] or by a gate voltage alone.[5-8] I will focus on ultrathin transition metal ferromagnets sandwiched between an oxide and a nonmagnetic heavy metal, in which magnetic, electronic and ionic effects at the interface can be exploited in new and unexpected ways.

I first focus on the heavy-metal/ferromagnetic interface, where spin-orbit coupling influences not only spin transport, but the nature of magnetism itself in the ferromagnet. In nonmagnetic heavy metals, spin-orbit coupling leads to a left-right scattering asymmetry such that spin "up" and spin "down" electrons pile up on either side of a material when a charge current flows through it. I will show how this spin Hall effect can be used to drive magnetization switching and domain wall motion in an adjacent ferromagnetic film,[1-4] and discuss its enhancement through interface engineering[5]. In these same materials, broken inversion symmetry can lift the chiral degeneracy and generate new topological spin textures such as spin-spirals and skyrmions through the interfacial Dzyaloshinskii-Moriya interaction (DMI). I will show that chiral magnetism can persist at room temperature in common transition metal ferromagnets[3,4], and discuss the role of DMI in domain wall dynamics[3,4] and spin-orbit torque switching[5]. I then show that DMI in engineered heterostructures can be used to stabilize room-temperature magnetic skyrmions[6], which have recently been proposed as scalable, thermally-stable bits for advanced spintronics devices. We have demonstrated the ability to generate stable skyrmion lattices and drive trains of individual skyrmions by short current pulses along a magnetic racetrack at speeds exceeding 100 m/s, opening the door to room-temperature skyrmion spintronics in robust thin-film heterostructures[6].

Finally, I will turn to the ferromagnet/oxide interface[7-11] and describe our discovery of a new class of "magneto-ionic" materials,[9,10] in which a gate voltage can be used to electrochemically switch the interfacial oxidation state to realize unprecedented control over magnetic properties. Here we use $Pt/Co/Gd_2O_{3-\delta}$ ultrathin film stacks, where $Gd_2O_{3-\delta}$ serves as an efficient oxygen ion conductor. I show that the magnetization in the thin Co layer can be switched between perpendicular and in-plane orientations, or quenched entirely, by driving O^{2-} towards or away from the Co/GdOx interface with a small gate voltage[10]. I then show that magneto-ionic gates can be used to locally tune magnetic properties to create a magnetic analog of field-effect transistors,[9] and to electrically control spin-orbit torques[11].

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